치의학석사학위논문

The effects of build angles on tissue surface adaptation of maxillary and mandibular complete denture bases manufactured by digital light processing

Digital Light Processing 기법으로 출력된 완전 레진 의치상의 조직면과 치조제 간 적합도에 출력각도가 미치는 영향

2019년 8월

서울대학교 대학원

치의학과 치과보철학 전공

JIN MEICEN

The effects of build angles on tissue surface adaptation of maxillary and mandibular complete denture bases manufactured by digital light processing

지도교수 한중석

이 논문을 치의학석사 학위논문으로 제출함

2009년 5월

서울대학교 대학원

치의학과 치과보철과 전공

JIN MEICEN

JIN MEICEN의 치의학석사 학위논문을 인준함

2009년 6월

위 원 장 ______________________ (인)

부위원장 ______________________ (인)

위 원 ______________________ (인)

−ABSTRACT−

The effects of build angles on tissue surface adaptation of maxillary and mandibular complete denture bases manufactured by digital light processing

JIN MEICEN, D.M.D.
Department of Prosthodontics, Graduate School, Seoul National University
*(Directed by Professor **Jung-Suk Han**, D.D.S., M.S.D., Ph.D.)*

Purpose: The effects of build angles on the tissue surface adaptation of complete denture bases manufactured by digital light processing (DLP) are unclear. The purpose of this in vitro study was to evaluate the effects of build angles on tissue surface adaptation of DLP-printed completed denture bases.

Materials and methods: Both maxillary and mandibular denture bases were virtually designed on reference casts and fabricated by the DLP technique. For each arch, a total of 40 denture bases were fabricated with 4 different build angle conditions (90, 100, 135, and 150 degrees) and divided into 4 groups (90D, 100D, 135D, and 150D; 10 denture bases per group). The scanned intaglio surface of each DLP denture base was superimposed on the scanned edentulous area of the reference cast to compare the degree of tissue surface adaptation. Root mean square estimate (RMSE), positive average deviation (PA), and negative average deviation (NA) values were measured and displayed with a color deviation map. The Mann-Whitney test and Kruskal-Wallis analysis of variance were used for statistical analyses (α = .05).

Results: No statistically significant differences were demonstrated for the RMSE among any build angle groups in either the maxillary or mandibular arch. With increase of build angles, the area of positive deviation in the maxillary arch moved from the palatal region to the posterior palatal seal area, and negative deviation became pronounced at the posterior tuberosities. In the maxillary arch, the 135D group exhibited favorable color distribution of surface deviation. In the mandibular arch, a positive deviation was detected at the labial slope to the crest of the ridge, whereas a negative deviation was observed at the buccal shelves and the retromolar pads. The 100D group showed a favorable distribution of surface deviation in the mandible.

Conclusions: In both arches, the difference of overall tissue surface adaptation was not statistically significant at the 4 build angles. However, the color deviation map revealed that the 135-degree build angle may be appropriate in the maxillary DLP-printed denture base, and the 100-degree angle in the mandibular denture base.

Keywords: Digital light processing, Complete denture bases, Build angle, Soft tissue adaptation

Student Number: 2017-25447

The effects of build angles on tissue surface adaptation of maxillary and mandibular complete denture bases manufactured by digital light processing

JIN MEICEN, D.M.D.

Department of Prosthodontics, Graduate School, Seoul National University
*(Directed by Professor **Jung-Suk Han**, D.D.S., M.S.D., Ph.D.)*

CONTENTS

I. INTRODUCTION

With extensive applications of computer-aided design and computer-aided manufacturing (CAD-CAM) technology in modern clinical dentistry, both subtractive and additive manufacturing methods are available for fabrication of implant surgical guides, casting patterns for fixed partial dentures and dental casts.[1,2,3] Digital light printing (DLP), one type of additive manufacturing technique, uses a digital micromirror device (DMD) and ultraviolet (UV) light to continuously build-up thin layers of photopolymerizable resin to create accurate three-dimensional (3D) objects.[4, 5] Recently, 3D-printable resin materials and printer systems have been commercially introduced to produce removable complete denture bases.[5, 6]

The feasibility of complete denture base milling from a polymethyl methacrylate block (PMMA) by a computer numeric controlled (CNC) machine was reported in 1994.[7] Complete denture fabrication using CAD-CAM technology will significantly simplify clinical and laboratory procedures, improve fit, and enable digital archiving to reproduce identical complete dentures in the future.[8, 9] With regard to tissue surface adaptation of CAD-CAM-generated denture bases, Goodacre et al. reported that milled denture bases exhibited more accurate and reproducible adaptation than conventional denture bases.[10] For 3D printing, the DLP-printed denture base has been reported to achieve clinically acceptable accuracy of tissue surface adaptation within 100 μm compared with to the milled denture base.[11, 12]

In the process of additive manufacturing, build angle refers to the direction with respect to which the object is sliced during the build-up process.[13, 14] Ollison and Berisso tested 3 different build angles (0, 45, and 90 degrees) to evaluate the effect of build direction on the form error of final printed objects.[15] They determined that error was the lowest at a 0-degree build angle and highest at a 90-degree angle. During the DLP process, several factors including the printable material, resolution of the printer, and build-up conditions can influence the degree of surface deviation.[16] To minimize possible distortion of 3D-printed objects, build angle should be carefully regulated.[15, 17] Recently, the optimal build angle was evaluated in the field of fixed prosthodontics.[14, 18] Alharbi et al. used 9 different build angles to evaluate the dimensional accuracy of complete-coverage dental restorations printed by the stereolithography (SLA) technique.[18] The authors recommended a 120-degree build angle to achieve the highest dimensional accuracy of an SLA-printed prosthesis.[18] For the DLP technique, Osman et al. recommended that the optimal build angle be 135 degrees for fabrication of fixed dental prostheses.[14] Another study reported that build direction affected the mechanical properties of 3D-printed dental restorations.[19]

The authors are unaware of a study that investigated the relationship between build angle in the DLP manufacturing process and tissue adaptation of completed denture base. Therefore, the purpose of this in vitro study was to evaluate the effects of build angles on tissue surface adaptation of DLP-printed completed denture bases in both maxillary and mandibular arches. The null hypothesis was that no difference would be found in degree of tissue surface adaptation of DLP-printed completed denture bases regardless of build angle.

II. MATERIALS AND METHODS

A pair of edentulous maxillary and mandibular casts with a morphology of American College of Prosthodontists (ACP) Type A were selected (Fig. 1).[11, 12] Other casts were excluded because of severe ridge resorption, excessive tissue undercuts, or poor cast qualities. The selected edentulous casts were scanned to obtain virtual maxillary and mandibular reference casts using a high-resolution laboratory scanner (Identica Blue T500; Medit), which can detect 10-μm differences. Based on the scanned reference cast, completed maxillary and mandible denture bases were virtually designed (3Shape Dental Designer, 3Shape) as reference CAD-designed denture base data. Using the reference CAD data, actual denture bases were fabricated using DLP-printable material (NextDent Base; NextDent) and a DLP-printer (Bio 3D W11; NextDent). The printer had a light-emitting diode (LED) light source of 405 nm wavelength, and the layer thickness of denture base printing was 100 μm. The mechanical properties of the printable material are shown in Table 1.

Four different build angles (90, 100, 135, and 150 degrees) were tested for the DLP-based denture base fabrication processes to create 4 denture base groups in both arches: Groups 90D, 100D, 135D, and 150D. First, the anterior labial surface of each maxillary and mandibular denture base was positioned perpendicular to the build platform (build angle = 90 degrees). The position of the denture base was then rotated 10, 45, and 60 degrees clockwise to obtain 100-, 135-, and 150-degree build angles (Fig 2). Since the tissue surface of the denture base was to be examined, support structures were located only on the polished denture surface. After printing, all the denture bases were cleaned in an ultrasonic bath with isopropyl alcohol for 10 minutes and subsequently polymerized for 15 minutes using an ultraviolet polymerization unit (LC 3DPrint Box; Bio3D) according to the manufacturer's instruction. Consequently, 40 maxillary and 40 mandibular denture bases were fabricated with 4 different build angle conditions (10 bases per angle).

All DLP-generated denture bases were scanned using a laboratory scanner (Identica Blue; Medit). Before scanning, each intaglio tissue surface of the printed denture base was treated using a scanning spray (EZ scan; Alphadent) with a 3 μm particle size. Each denture base was positioned on a silicone index (Exaflex putty; GC Corp) to ensure identical scanning direction in parallel with the scanner camera. The scanned data were stored in a standard tessellation language (STL) format and exported to a 3D-inspection software program (Geomagic Control X, 3D Systems). The scanned file of the reference cast was superimposed on the STL file of the intaglio surface of each denture base to evaluate the tissue surface adaptations. Before superimposition analysis, virtual trimming of the denture base scan data irrelevant to tissue surface adaptation, such as polished or occlusal surfaces, was performed. Three pairs of corresponding points were selected on the tissue surface of each scanned reference cast and denture base to achieve primary alignment. A best-fit alignment was then performed based on the primary alignment. A color-coded deviation map was also displayed for each superimposition analysis. The nominal was set at ±50 μm, and the critical deviation at ±300 μm. For controlled surface matching, each superimposition analysis was conducted on the tissue area of the scanned reference cast and the corresponding tissue surface of each scanned denture base. Surface deviation data of root-mean-square estimate (RMSE), positive average deviation (PA), and negative average deviation (NA) values were calculated to report the degree of tissue surface adaptation. Each scanning and superimposition process was performed by a single investigator.

Means, standard deviations, medians, and interquartile ranges of all surface deviation measurements (RMSE, PA, and NA) were calculated. To evaluate the effect of build angle on the degree of tissue surface adaptation among the denture base groups in both arches, Kruskal-Wallis analysis was conducted. Based on the Levene test, the assumption of homogeneity of variances for the measured data was violated. A post hoc multiple comparison test was conducted using the Mann-Whitney test and corrected with the Bonferroni method. All statistical analyses were performed using a software program (SPSS Statistics v22.0; IBM Corp) (α = .05).

III. RESULTS

The descriptive statistics (mean, standard deviation, median, and interquartile range) of the RMSE values of all groups are presented in Table 2, PA values in Table 3, and NA values in Table 4. No statistically significant differences in RMSE value were observed among the groups in either the maxillary (P = .610) or mandibular (P = .100) arch. In the mandible, however, the 100D group exhibited the lowest RMSE values (Fig 3). For the PA value in the maxillary arch, there were statistically significant differences among the denture base groups ($P < .001$, Fig. 4). The 135D and 150D groups exhibited significantly lower PA values than the 90D group (both $P < .001$). The PA value of the 100D group was also significantly higher than those of the 135D and 150D groups (both $P < .001$). However, the 90D group was not significantly different from the 100D group ($P = .144$). However, the NA values were not statistically different among the denture base groups

in the maxillary arch ($P = .774$). For the mandibular arch, the differences in PA values ($P = .348$, Fig. 5) and NA values ($P = .063$, Fig. 5) among the denture base groups were not statistically significant. However, both PA and NA values were lowest in the 100D group.

Both the maxillary and mandibular reference CAD denture bases exhbited excellent tissue surface adaptation to the tissue area of the reference cast scan data within ± 50 μm deviation (Fig. 6). However, for the DLP denture bases in the maxillary arch, the area of positive deviation (yellow to red) was displayed at the mid-palatal area in the 90D group (Fig. 7). As the build angle increased, the positive deviation area broadened to the hard palate (100D) and moved to the posterior palatal seal area (150D). The color map revealed adequate tissue surface adaptation in the 135D group, with a wide green-colored area on the entire palate. The area of negative deviation (blue) also changed with increase in build angle, moving from the crest of the posterior residual ridge (90D) to the posterior tuberosity (150D). For the DLP denture bases in the mandibular arch, the area of positive deviation was detected at the labial slope of the anterior residual ridge and the retromylohyoid area for all groups (Fig. 8). The deviation area moved from the slope of the anterior ridge (90D) to the crest of the anterior ridge (150D) with an increase in build angle. The area of negative deviation moved from the buccal slope of the posterior ridge (90D) to the lingual surface near the crest of the anterior ridge, buccal shelf area, and retromolar pads (150D) with an increase in build angle.

IV. DISCUSSION

Based on the results of this study, no statistically significant difference was found in the overall tissue surface adaptation (RMSE values) of DLP denture bases fabricated with different build angles in either the maxillary or mandibular arch. Therefore, the null hypothesis was not rejected.

According to the color deviation map based on this superimposition study, the area of positive deviation indicated a space between the denture base and the edentulous tissue surface. The negative deviation area indicated mucosal compression or tissue impingement on the edentulous tissue surface. In the maxillary arch, the color map revealed a space between the denture base and tissue surface from the hard palate to the posterior palatal seal area. In a clinical context, the horizontal portion of the hard palate is classified as a stress-bearing area that offers physiological resistance to deformation and withstands masticatory forces.[20] In the 90D, 100D, and 135D groups, the space at the palatal region or the posterior palatal seal area may decrease retention of the denture base and result in an inadequate border seal. In contrast, regardless of the build angle, mucosal compression or impingement was mainly detected at the buccal slope of the posterior residual ridge and posterior tuberosity. Clinically, those areas need to be relieved to protect the vulnerable nonattached gingiva from excessive compression or inflammatory degeneration. Based on the color deviation map, although some areas should be clinically relieved, a 135-degree build angle may be recommended in the maxillary arch to guarantee favorable denture base adaptation.

In the mandibular arch, however, the color map of the 100D group exhibited more favorable distribution of surface deviation than that those of the other groups. For the denture base groups with 135- or 150-degree build angles, excessive tissue impingement (negative deviation) at the retromolar pads may not be favorable for support and stability of the denture base. However, irrespective of build angle, a space (positive deviation) was detected at the mylohyoid ridge and retromylohyoid fossa areas. Clinically, the mylohyoid ridge and retromylohyoid fossa often need to be relieved during creation of the impression. Therefore in the mandibular arch, a 100-degree build angle can be recommended for a DLP completed denture base to provide favorable tissue surface adaptation.

In this study, as the build angle changed, the color distribution pattern of the positive or negative deviation areas also change. Based on previous studies, build angle was reported to affect the dimensional accuracy of 3D-printed output.[15, 17] The build angle of printed objects in the platform may also affect the sectional area of sliced images and the number of sliced layers.[16] In addition, an area of positive deviation on the intaglio surface of the printed prosthesis was observed close to the support structure.[12, 14] This may be related to changes in the location of support structures according to change of build angle. The upward movement of the DLP platform and sagging of the 3D printable material may also play an important role in surface deviation of the DLP denture base.

The optimal build angle (135 degrees) in the maxilla was consistent with a previous study in which complete-coverage dental restoration with the most favorable deviation pattern was achieved with a 135-degree build angle in a DLP technique.[14] However, the optimal build angle for the DLP-printed mandibular denture base was 100 degrees, which differed from the previous findings.[14] This may result from differences in geometry of dental restorations or morphology of edentulous arches.[14] The different printing mechanisms and printable materials could also have an effect on the optimal build angle. To guarantee intimate tissue surface adaptation, maxillary or mandibular conditions must be considered to select the optimal build angle for DLP-printed denture bases.

The degree of surface deviation measured in this superimposition study may not be sufficient to determine the degree of mucosal retention of DLP denture bases. In a previous study, soft tissue displacement between the range of 375 and 500 μm was measured on the denture base in the maxillary arch, which is higher than the critical deviation (300 μm) in this study.[11, 21] Since the amount of edentulous tissue displacement required for effective retention of denture bases has yet to be clearly defined, clinical quantitative evaluation of DLP denture base should be performed.

A limitation of this in vitro study was that tissue surface adaptation of completed denture bases was only evaluated in vitro. The experimental conditions did not simulate the oral environment or assess the dynamic characteristics of soft tissue compression or distortion. In addition, a 180-degree build angle was not tested in this study because the dimension of each maxillary and mandibular denture base was slightly larger than the inherent size of the DLP printer build platform. Although not quantitatively verified, each denture base was positioned as parallel as possible to the camera of the scanner to ensure an identical scanning direction throughout the testing procedure. Various factors such as support structure distribution, reliability of the coregistration algorithm, accuracy of the laboratory scanner, different morphology of the residual ridge, and the mechanical properties of printable denture materials need to be evaluated in future studies.

V. CONCLUSIONS

Based on the findings of the in vitro study, the following conclusions were drawn:

1. DLP is a promising additive manufacturing technique for fabrication of completed denture bases.

2. The difference of overall tissue surface adaptation was not statistically significant among DLP-printed denture bases,

regardless of build angle.

3. However, the color deviation map showed that the build angle suggested for DLP−printed completed denture bases was 135 degrees in the maxilla and 100 degrees in the mandible.

REFERENCES

1. Dawood A, Marti BM, Sauret−Jackson V, Darwood A. 3D printing in dentistry. Br Dent J 2015;219:521.

2. Miyazaki T, Hotta Y, Kunii J, Kuriyama S, Tamaki Y. A review of dental CAD−CAM: current status and future perspectives from 20 years of experience. Dent Mater J 2009;28:44−56.

3. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: an overview of recent developments for CAD−CAM generated restorations. Br Dent J 2008;204−505.

4. Barazanchi A, Li KC, Al−Amleh B, Lyons K, Waddell JN. Additive technology: update on current materials and applications in dentistry. J Prosthodont 2017;26:156−63.

5. Stansbury JW, Idacavage MJ. 3D printing with polymers: challenges among expanding options and opportunities. Dent Mater J 2016;32:54−64.

6. NextDent dental materials for 3D printing. Available from: https://nextdent.com/vertex−dental−bv−presents−class−iia−nextdent−dental−materials−for−3d−printing.

7. Maeda Y, Minoura M, Tsutsumi S, Okada M, Nokubi T. A CAD−CAM system for removable denture. Part I: Fabrication of complete dentures. Int J Prosthodont 1994;7:17−21.

8. Kattadiyil MT, AlHelal A, An update on computer−engineered complete dentures: a systematic review on clinical outcomes. J Prosthet Dent 2017;117:478−85.

9. Bidra AS, Taylor TD, Agar JR. Computer−aided technology for fabricating complete dentures: systematic review of historical background, current status, and future perspectives. J Prosthet Dent 2013;109:361−6.

10. Goodacre BJ, Goodacre CJ, Baba NZ, Kattadiyil MT. Comparison of denture base adaptation between CAD−CAM and conventional fabrication techniques. J Prosthet Dent 2016;116:249−56.

11. Hwang H−J, Lee SJ, Park E−J, Yoon H−I. Assessment of the trueness and tissue surface adaptation of CAD−CAM maxillary denture bases manufactured using digital light processing. J Prosthet Dent, in press.

12. Yoon H−I, Hwang H−J, Ohkubo C, Han J−S, Park E−J. Evaluation of the trueness and tissue surface adaptation of CAD−CAM mandibular denture bases manufactured using digital light processing. J Prosthet Dent, in press.

13. Oropallo W, Piegl LA. Ten challenges in 3D printing. Eng Comput 2016;32:135−48.

14. Osman RB, Alharbi N, Wismeijer D. Build Angle: does it influence the accuracy of 3D−printed dental restorations using digital light−processing technology? Int J Prosthodont 2017;30:192−8.

15. Ollison T, Berisso K. Three−dimensional printing build variables that impact cylindricity. J Ind Technol 2010;1:1−10.

16. Prashant K, Anne M, Debasish D. A review of process planning techniques in layered manufacturing. Rapid Prototyp J 2000;6:18−35.

17. Pulak MP, N. VR, G. DS. Slicing procedures in layered manufacturing: a review. Rapid Prototyp J 2003;9:274−88.

18. Alharbi N, Osman RB, Wismeijer D. Factors influencing the dimensional accuracy of 3D−printed full−coverage dental restorations using stereolithography technology. Int J Prosthodont

2016;29:503−10.

19. Alharbi N, Osman R, Wismeijer D. Effects of build direction on the mechanical properties of 3D−printed complete coverage interim dental restorations. J Prosthet Dent 2016;115:760−7.

20. Van Scotter DE, Boucher LJ. The nature of supporting tissues for complete dentures. J Prosthet Dent 1965;15:285−94.

21. Wills DJ, Manderson RD. Biomechanical aspects of the support of partial dentures. J Dent 1977;5:310−8.

TABLES

Table 1. Mechanical properties of the printable materials used as described by the manufacturer

Material	Property	Value
NextDent Base	Brookfield viscosity at 23℃ (Pa·s)	1.0 – 1.5
	Flexural strength (MPa)	80 – 95
	Flexural modulus (MPa)	2.000 – 2.400
	Charpy impact resistance (KJ/m^2)	10 – 14
	Water sorption (μg/mm^2)	< 32
	Water solubility (μg/mm^2)	< 4
	Residual monomer (%)	< 1
	Hardness (Shore D)	80 – 90

Table 2. Mean (standard deviation), median, and interquartile range values of the measured root mean square estimates (RMSE) between scanned master casts and denture bases groups fabricated by digital light processing (DLP) with 4 build angles: 90D, 100D, 135D, and 150D

Build Angle Groups	90D		100D		135D		150D	
	Maxilla	Mandible	Maxilla	Mandible	Maxilla	Mandible	Maxilla	Mandible
Mean	0.0946	0.1135	0.0790	0.1032	0.0873	0.1225	0.0883	0.1364
SD	±0.0081	±0.0051	±0.0026	±0.0067	±0.0056	±0.0077	±0.0056	±0.0145
Median	0.0858	0.1159	0.0758	0.0958	0.0912	0.1276	0.0849	0.1263
Interquartile Range	0.0540	0.0298	0.0149	0.0304	0.0328	0.0467	0.0294	0.0640

* SD: Standard deviation

Table 3. Mean, standard deviation (SD), median, and interquartile range values of measured 3-dimensional surface deviations (positive and negative average values) between the scanned master cast and maxillary DLP-printed denture base groups at 4 build angles: 90D, 100D, 135D, and 150D

Build Angle Groups	90D		100D		135D		150D	
	(+)Average	(−)Average	(+)Average	(−)Average	(+)Average	(−)Average	(+)Average	(−)Average
Mean	0.0612	−0.0825	0.0531	−0.0743	0.0385	−0.0717	0.0376	−0.0735
SD	±0.0019	±0.0068	±0.0021	±0.0017	±0.0035	±0.0042	±0.0017	±0.0055
Median	0.0585	−0.0762	0.0527	−0.0724	0.0348	−0.0721	0.0363	−0.0710
Interquartile Range	0.0105	0.0461	0.0059	0.0076	0.0121	0.0255	0.0048	0.0264

* SD: Standard deviation, (+) Average: positive average value, (−) Average: negative average value

Table 4. Mean, standard deviation (SD), median, and interquartile range values of measured 3-dimensional surface deviations (positive and negative average values) between the scanned master cast and mandibular DLP-printed denture bases at 4 build angles: 90D, 100D, 135D, and 150D

Build Angle Groups	90D		100D		135D		150D	
	(+)Average	(−)Average	(+)Average	(−)Average	(+)Average	(−)Average	(+)Average	(−)Average
Mean	0.0954	−0.0889	0.0899	−0.0732	0.1054	−0.0819	0.0967	−0.1020
SD	±0.0026	±0.0060	±0.0052	±0.0055	±0.0068	±0.0052	±0.0077	±0.0099
Median	0.0980	−0.0896	0.0846	−0.0725	0.1076	−0.0806	0.0858	−0.0962
Interquartile Range	0.0140	0.0347	0.0221	0.0315	0.0398	0.0348	0.0357	0.0521

* SD: Standard deviation, (+) Average: positive average value, (−) Average: negative average value

FIGURES

Fig. 1. Maxillary and mandibular edentulous master casts with residual ridge morphology of class I–type A based on the classification of the American College of Prosthodontists. A, Maxillary cast. B, Mandibular cast.

A

B

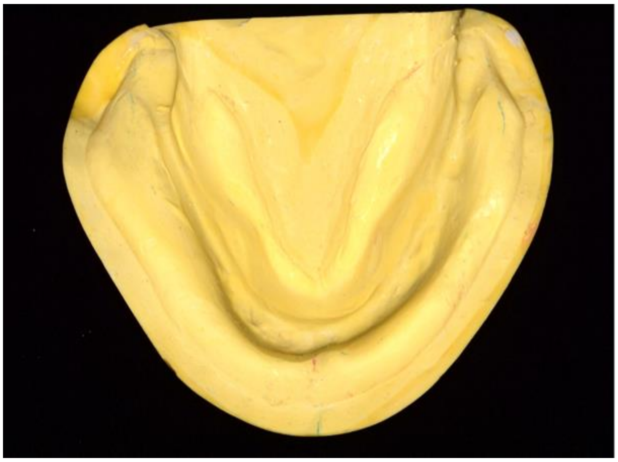


Fig. 2. Reference CAD–designed denture bases positioned on the build platform during digital light processing (DLP) at 4 build angles. A. Maxillary denture base, 90–degrees, B. Mandibular denture base, 90–degrees, C. Maxillary denture base, 100–degrees, D. Mandibular denture base, 100–degrees, E. Maxillary denture base, 135–degrees, F. Mandibular denture base, 135–degrees, G. Maxillary denture base, 150–degrees, H. Mandibular denture base, 150–degrees.

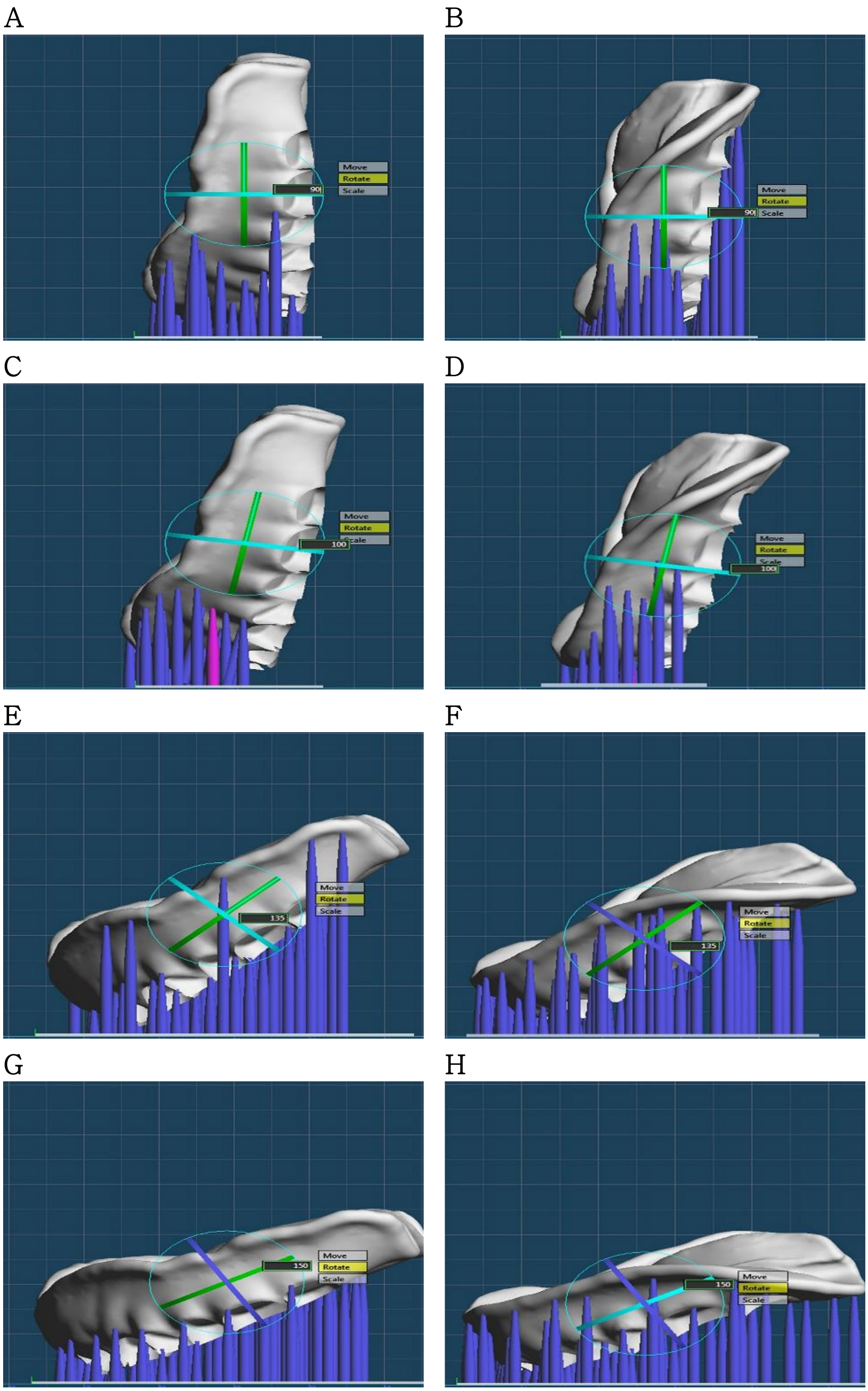
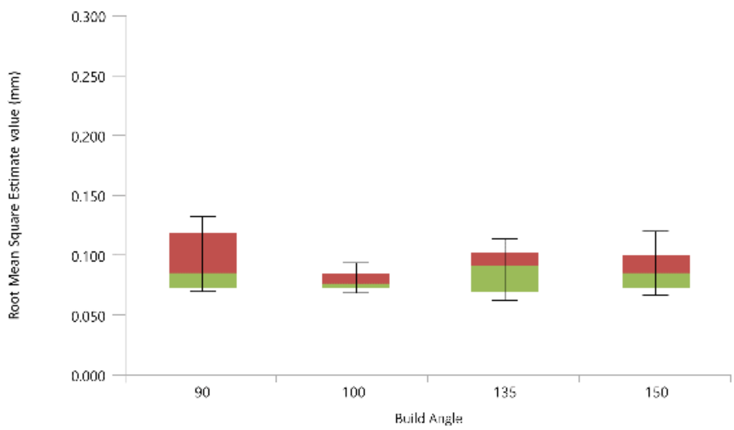

A
Move
Rotate
Scale
90
B
Move
Rotate
Scale
90
C
Move
Rotate
Scale
100
D
Move
Rotate
Scale
100
E
Move
Rotate
Scale
135
F
Move
Rotate
Scale
135
G
Move
Rotate
Scale
150
H
Move
Rotate
Scale
150

Fig. 3. Boxplots of overall tissue surface adaptations (root−mean−square estimates) of maxillary and mandibular denture bases fabricated by DLP technique at 4 build angles: 90, 100, 135, and 150. Line where the red box meets the green box represents the median. The red box represents the first quartiles of measurement; the green box represents the third quartiles of measurement. The upper horizontal bar represents the maximum value; the lower horizontal bar represents the minimum value. No significant difference was found among the groups of maxillary and mandibular denture bases (Kruskal−Wallis). A, Maxillary denture bases (P = .610). B, Mandibular denture bases (P = .100).

A



B

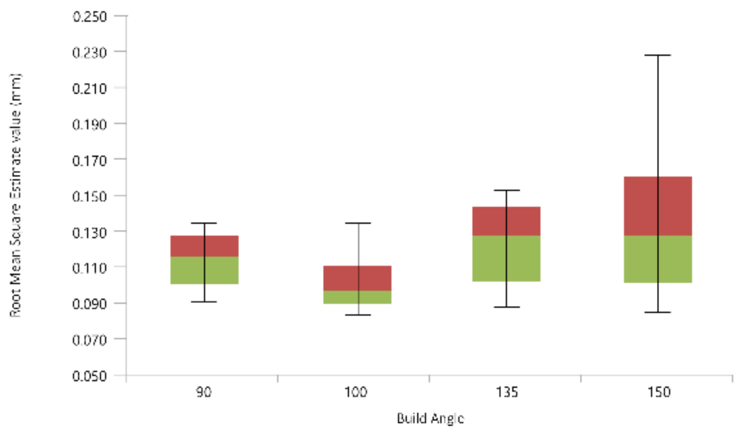
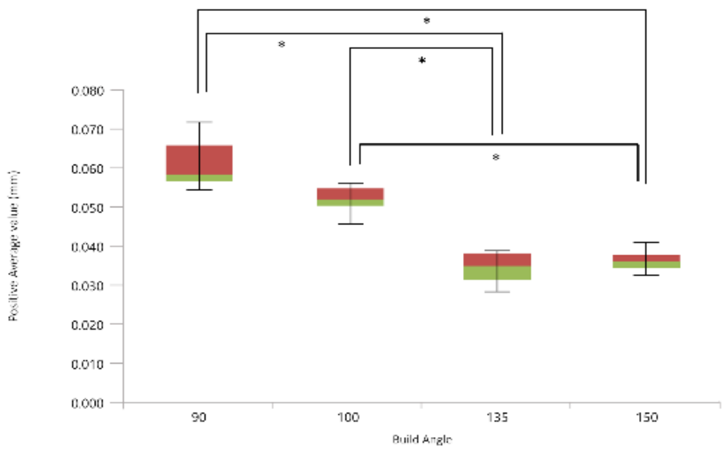


Fig. 4. Boxplots of tissue surface adaptation (positive average and negative average) of maxillary denture bases fabricated by the DLP technique at 4 build angles: 90, 100, 135, and 150. Line where the red box meets the green box represents the median. The red box represents the first quartiles of measurement; the green box represents the third quartiles of measurement. The upper horizontal bar represents the maximum value; the lower horizontal bar represents the minimum value. A, Positive average, significant differences among groups marked as an asterisk (*, $P < .001$, Mann-Whitney U test) B, Negative average, no significant difference among the groups ($P = .144$, Kruskal-Wallis).

A



B

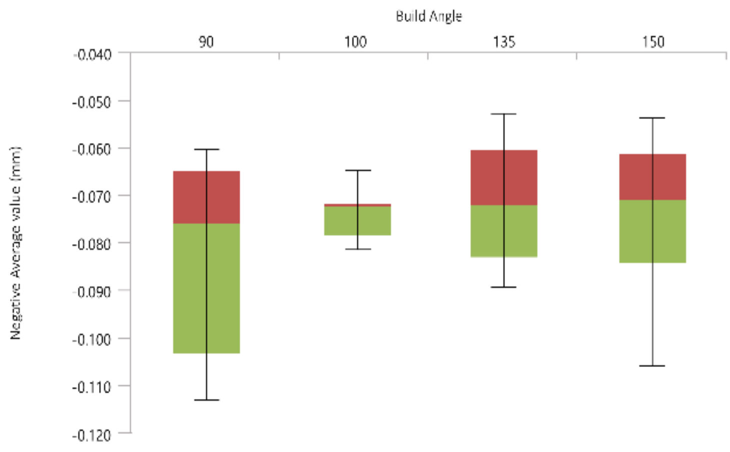
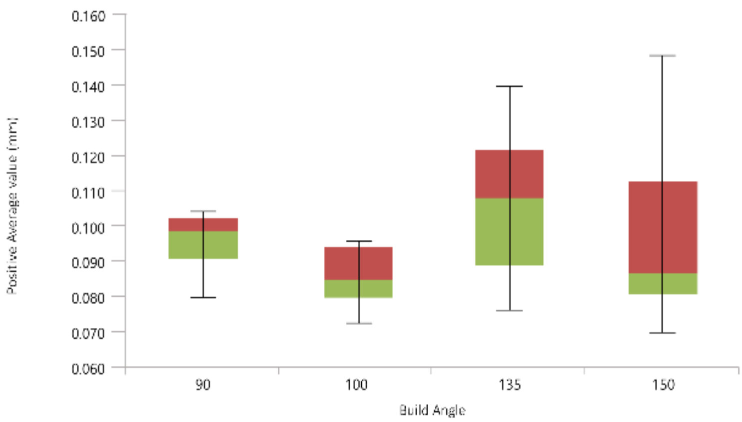


Fig. 5. Boxplots of tissue surface adaptation (positive average and negative average) of mandibular denture bases fabricated by the DLP technique at 4 build angles: 90, 100, 135, and 150. The line where the red box meets the green box represents the median. The red box represents the first quartiles of measurement; the green box represents the third quartiles of measurement. The upper horizontal bar represents the maximum value; the lower horizontal bar represents the minimum value. No significant difference among the groups of maxillary and mandibular denture bases (Kruskal–Wallis). A, Positive average (P = .348), B, Negative average (P = .063).

A



B

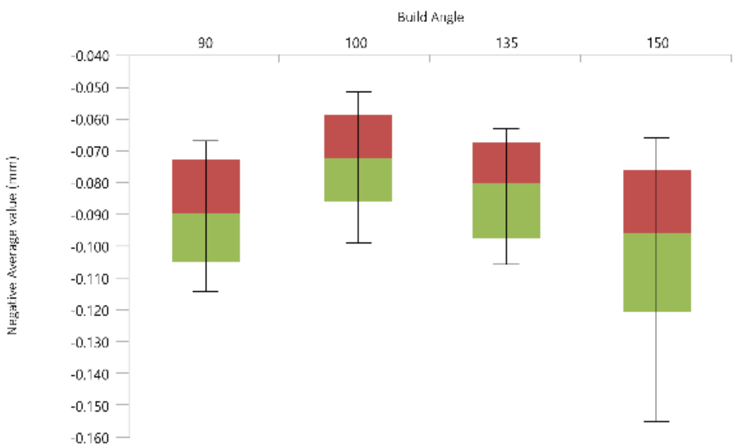


Fig. 6. Color deviation maps of tissue surface adaptation of reference CAD–designed denture bases. A, Maxillary denture base. B, Mandibular denture base. For both arches, measured surface deviation less than 50 μm is displayed in green.

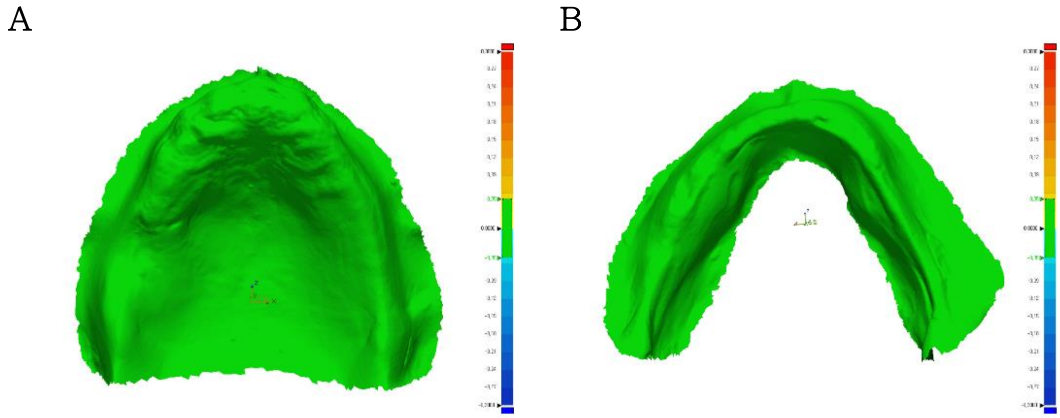


Fig. 7. Color maps of tissue surface adaptation of maxillary denture bases fabricated by the DLP technique at 4 build angles: A.90, B.100, C.135, and D.150. Positive deviation is displayed with yellow to red, and negative deviation with cyan to blue.

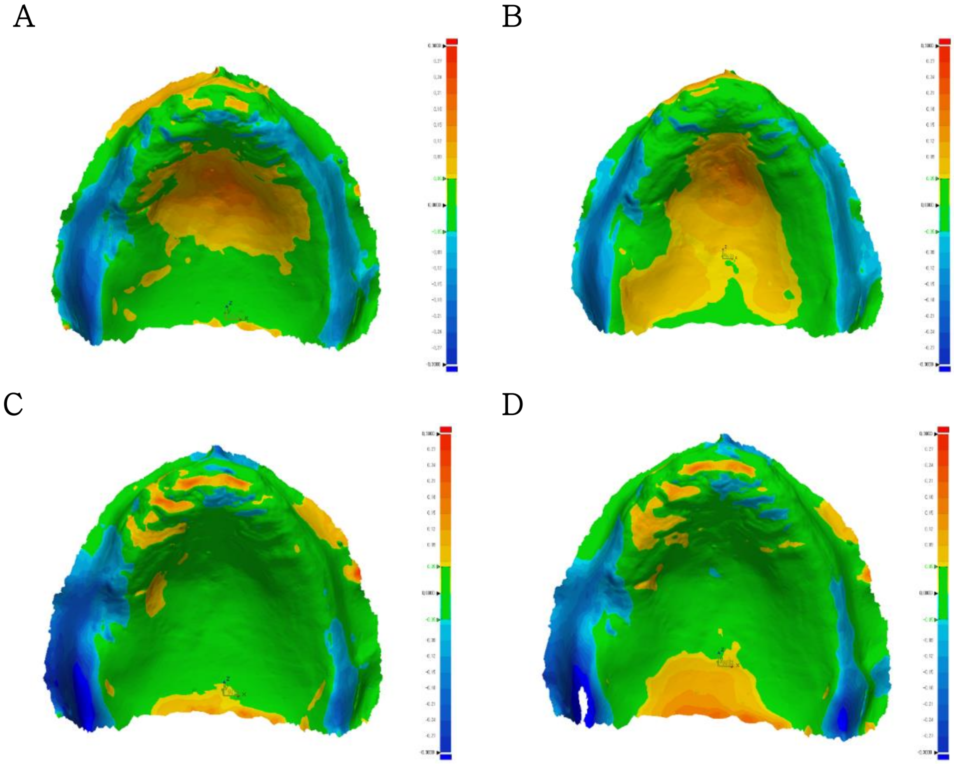
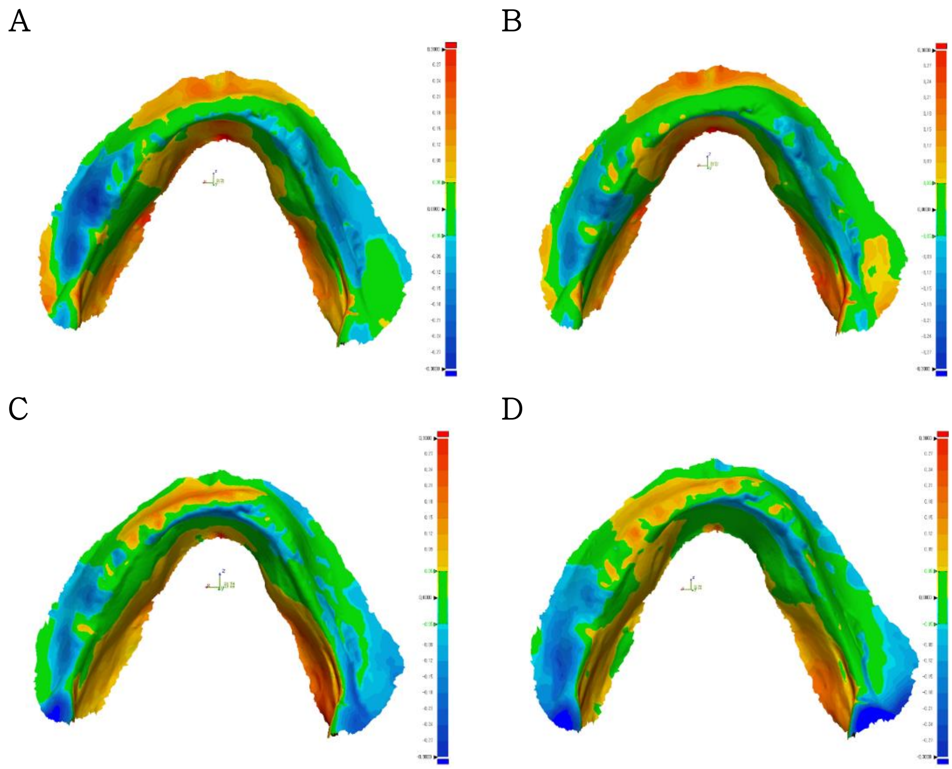


Fig. 8. Color maps of tissue surface adaptation of mandibular denture bases fabricated by the DLP technique at 4 build angles: A.90, B.100, C.135, and D.150. Positive deviation is displayed with yellow to red, and negative deviation with cyan to blue.



국문초록

Digital Light Processing 기법으로 출력된 완전 레진 의치상의 조직면과 치조제 간 적합도에 출력각도가 미치는 영향

서울대학교 대학원 치의학과 치과보철과 전공(지도교수 한중석)

JIN MEICEN

본 연구의 목적은 Digital Light Processing(DLP)방식의 3D 프린팅 기법을 이용하여 다양한 출력각도 조건에서 제작된 총의치상의 조직내면 적합도를 평가하는 것이다.

ACP type A형 치조제 형태를 가진 완전 무치악 상, 하악 주모형 스캔하여 얻은 데이터를 사용하여 상,하악 CAD 의치모델를 디자인하였고 이것을 기반으로 총 4가지 출력각도 (90°, 100°, 135°, 150°)를 설정하여 DLP방식으로 각각 10개의 상, 하악 총의치상을 제작하였다. 주모형 및 제작된 모든 총의치상의 조직내면을 모델스캐너 (Identica Blue T500; Medit)로 스캔하여 STL 파일을 얻었다. 그 후 주모형의 스캔 데이터를 레퍼런스로 설정하여 CAD 의치모델 및 제작된 총의치상들과 중첩 프로그램 (Geomagic Control X; 3D Systems)을 사용하여 각각 중첩분석을 진행하였고 의치상 조직내면 적합도에 출력각도가 미치는 영향에 대해 평가하였다. Root mean square estimate (RMSE), positive average deviation (PA), and negative average deviation (NA)들을 color deviation map으로 측정 및 표시하였다. Mann-Whitney 검정 및 Kruskal-Wallis analysis 분산을 사용하여 통계 분석을 하였다. 통계적 유의수준은 $p<0.05$로 검정하였다.

4가지 출력각도로 제작된 상, 하악 총의치상의 조직내면 적합도를 비교하였을 때 RMSE 값에서 통계적 유의성은 없었다. 그러나 출력각도가 증가함에 따라 상악 총의치상의 PA영역이 구개부에서 후방 구개 폐쇄부로 이동하고 NA영역은 상악결절에서 증가되는 양상을

보였다. 하악 총의치의 PA영역은 전치부 순측 치조제에서 치조제 정상으로 이동하였고 NA영역은 협붕과 후구치 삼각융기부에서 나타났다. 그러므로 DLP방식으로 제작한 상하악 총의치상에서 조직면 적합도는 출력각도에 따른 통계적 유의성이 나타나지 않았지만 color map deviation을 통하여 상악에서 135도의 출력각도로 제작한 의치상의 조직내면 적합도가 가장 좋은 결과를 보여주었고 하악에서 100도의 출력각도로 제작한 의치상의 조직내면 적합도가 가장 좋은 결과를 보였다.

주요어 : Digital light processing, Complete denture bases, Build angle, Soft tissue adaptation

학 번 : 2017-25447